

CLAIMS

1. An optical spectrum analyser comprising: a length of optical fibre for receiving an input optical signal; a tuneable optical filter in optical communication with the input fibre, the tuneable optical filter including a first in-fibre Bragg grating inscribed in a first section of fibre, and means operable to → apply a variable axial force to the first section of fibre, to thereby tune the peak wavelength of the grating over a desired wavelength range; and optical detection means operable to detect an optical signal selected by the tuneable optical filter.
2. An optical spectrum analyser according to claim 1 in which the tuneable optical filter includes first and second in-fibre Bragg gratings inscribed in first and second sections of fibre respectively, the spectra of the gratings having different peak wavelengths.
3. An optical spectrum analyser according to claim 1 or 2 in which the said means is operable to apply a variable axial force to one or each of the first and second sections of fibre.
4. An optical spectrum analyser according to any preceding claim in which the optical spectrum analyser is for use with a multi-channel optical system, the channels being substantially equally spaced in wavelength space.
5. An optical spectrum analyser according to any of claims 2 to 4 in which the peak wavelengths of the gratings are tuneable over different wavelength ranges, the ranges being of substantially the same spectral width.
6. An optical spectrum analyser according to claim 5 in which the wavelength tuning ranges substantially abut or overlap in wavelength space.
7. An optical spectrum analyser according to claim 6 in which the combined wavelength tuning range of the two gratings extends from approximately 1530

nanometers to approximately 1560 nanometers.

8. An optical spectrum analyser according to claim 6 in which the combined wavelength tuning range of the two gratings may extend from approximately 1580 nanometers to approximately 1620 nanometers.

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9. An optical spectrum analyser according to any preceding claim in which the full width half maximum spectral bandwidth of the or each grating is between 0.05 nanometers and 0.5 nanometers.

10. An optical spectrum analyser according to any preceding claim in which the side-lobe suppression ratio of the or each grating is greater than -20dB.

11. An optical spectrum analyser according to any preceding claim in which the axial force is strain.

12. An optical spectrum analyser according to claim 11 in which the peak wavelength of each grating, when unstrained, is less than the wavelengths of the optical channels present within the respective wavelength tuning ranges of the gratings.

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13. An optical spectrum analyser according to any preceding claim in which an optical signal selected by the tuneable optical filter is reflected by only one grating.

14. An optical spectrum analyser according to claim 13 in which the optical spectrum analyser further comprises an optical fibre signal routing means.

15. An optical spectrum analyser according to claim 14 in which the optical fibre signal routing means comprises a first optical fibre coupler, one leg on one side of the coupler being communicatively connected to the input fibre and one leg on the other side of the coupler being communicatively connected to the tuneable optical filter.

16. An optical spectrum analyser according to claim 15 in which an optical isolator is provided between the input fibre and the one leg on one side of the coupler.

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17. An optical spectrum analyser according to any of claims 2 to 16 in which the first and second sections of fibre are located within a grating length of optical fibre, the grating length of fibre being long compared to the lengths of said sections.

18. An optical spectrum analyser according to claim 17 in which the first and second sections of fibre, and hence the gratings, are spatially separate within the grating length of fibre.

19. An optical spectrum analyser according to claim 17 in which the first and second sections of fibre are the same section of fibre, the gratings being inscribed in the same section of fibre and thus being superimposed one upon the other.

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20. An optical spectrum analyser according to any of claims 4 to 19 in which the difference in the peak wavelengths of the gratings is equal to the wavelength spacing of the optical channels multiplied by a numerical factor.

21. An optical spectrum analyser according to claim 19 in which the numerical factor is equal to an integer plus a fraction of one, such as one half or one third.

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22. An optical spectrum analyser according to any of claims 17 to 21 in which the grating length of optical fibre is mounted on the means operable to apply a variable strain, to thereby enable a variable strain to be applied to the first and second sections of fibre, and hence to both gratings, at the same time.

23. An optical spectrum analyser according to any of claims 15 to 22 in which the optical detection means is communicatively connected to the second leg on the one side of the first coupler.

24. An optical spectrum analyser according to claim 23 in which the optical detection means comprises a first photodetector.
25. An optical spectrum analyser according to claim 24 in which the optical detection means further comprises a second optical fibre coupler, one leg on one side of the second coupler being communicatively connected to the photodetector, and one leg on the second side of the second coupler being communicatively connected to the second leg on the one side of the first coupler, and a second photodetector communicatively connected to the second leg on the second side of the second coupler.
26. An optical spectrum analyser according to claim 25 in which the optical detection means further comprises a broadband, in-fibre optical filter, in the form of a chirped in-fibre Bragg grating communicatively connected between the first photodetector and the one leg on one side of the second coupler.
27. An optical spectrum analyser according to claim 26 in which the optical bandwidth of the chirped Bragg grating substantially extends over the wavelength tuning range of one of the two gratings, such that the chirped Bragg grating reflects an optical signal reflected by the said one grating to the second photodetector and transmits an optical signal reflected by the other grating to the first photodetector.
28. An optical spectrum analyser according to claim 25 in which the optical detection means further comprises a broadband, in-fibre optical filter communicatively connected to the second leg on the one side of the second coupler, the optical filter reflecting an optical signal reflected by either grating to the second photodetector.
29. An optical spectrum analyser according to claim 28 in which the reflectivity of the optical filter varies as a function of wavelength across the optical bandwidth of the optical filter.
30. An optical spectrum analyser according to claim 29 in which the optical

filter is a chirped in-fibre Bragg grating.

31. An optical spectrum analyser according to claim 29 in which the optical filter is an in-fibre sampled grating.

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a7* 32. An optical spectrum analyser according to any of claims 28 to 31 in which the optical spectrum analyser further includes means operable to compare the output signals of the first and second photodetectors, to thereby determine the wavelength of the optical signal reflected from one of the gratings.

33. An optical spectrum analyser according to claim 32 in which the said means is operable to calculate the ratio of the amplitude of the output signal of the first photodetector to the amplitude of the output signal of the second photodetector, the ratio being indicative of the wavelength of the signal reflected from one of the gratings.

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a8* 34. An optical spectrum analyser according to any of claims 2 to 16 in which the first and second sections of fibre are provided in physically separate first and second grating lengths of optical fibre, the grating lengths of fibre being physically long compared to the said sections.

35. An optical spectrum analyser according to claim 34 in which two optical detection means are provided, a first optical detection means being communicatively connected between one leg on the second side of the first coupler and the first grating length, and a second optical detection means being communicatively connected between the second leg on the second side of the first coupler and the second grating length.

36. An optical spectrum analyser according to claim 35 in which the detection means each comprise a further optical coupler communicatively connected to the respective grating lengths, the respective legs on the first coupler and to a photodetector; one leg on one side of the further optical coupler is communicatively connected to the respective one of the legs on the

second side of the first coupler, the second leg on the one side of the further coupler is communicatively connected to the photodetector, and one leg on the second side of the further coupler is communicatively connected to the respective grating length.

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37. An optical spectrum analyser according to any of claims 34 to 36 in which each of the grating lengths of fibre is mounted on a separate means operable to apply a variable strain to a respective one of the first and second sections of fibre, the said means being operable to enable a variable strain to be applied to each of the first and second sections of fibre at either the same time or at different times.

38. An optical spectrum analyser according to claim 14 in which the optical fibre signal routing means is an optical fibre circulator.

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39. An optical spectrum analyser according to any of claims 2 to 38 in which the tuneable optical filter includes more than two in-fibre Bragg gratings, each grating being inscribed in a respective section of fibre.

40. An optical spectrum analyser according to any of claims 24 to 39 in which the optical spectrum analyser further comprises means operable to reduce the signal to noise ratio in the output signal of a or each photodetector, the said means comprising phase-lock loop apparatus connected to the respective means for applying a variable strain and the said photodetector.

41. An optical spectrum analyser according to any of claims 11 to 40 in which the means operable to apply a variable strain comprises a spaced pair of mandrels, the part of the grating length of fibre including the section or sections of fibre including one or more gratings being mountable therebetween.

42. An optical spectrum analyser according to claim 41 in which the mandrels are shaped to avoid sharply bending an optical fibre wound therearound, and are substantially cylindrical in shape.

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43. An optical spectrum analyser according to claim 41 or 42 in which the mandrels are fabricated from a material which minimises the forces acting between the mandrel and the fibre coating without abrading or chemically altering the fibre coating; such as a self-lubricating material, such as graphite.
44. An optical spectrum analyser according to any of claims 41 to 43 in which a continuous groove is provided around the outer surface of each mandrel, for receiving the parts of the grating length of fibre on either side of the section or sections of fibre including one or more gratings, the groove extending for a plurality of turns around the mandrel, to enable the said lengths of fibre to complete a sufficient number of turns around the mandrel to be held in place on the mandrel by means of frictional forces.
45. An optical spectrum analyser according to any of claims 41 to 44 in which the mandrels are movably mounted on a mounting member, one mandrel being rotatably mounted on the mounting member on a motor means operable to rotate the said mandrel.
46. An optical spectrum analyser according to any of claims 41 to 45 in which the means operable to apply a variable strain further comprises a elongate member, in the form of a metal beam, mounted on one end of the other mandrel and extending to a stop member provided on the mounting member, rotation of the one mandrel exerting a pulling force on the fibre mounted between the mandrels, thereby causing rotation of the other mandrel until the elongate member abuts the stop member, further rotation of the other mandrel thereby being prevented, such that a further rotation of the one mandrel causes strain to be applied to the said fibre and the elongate member.
47. An optical spectrum analyser according to any of claims 11 to 46 in which the means operable to apply a variable strain is athermalised.
48. An optical spectrum analyser according to claim 46 or 47 in which an electrical strain gauge is provided on the elongate member, the strain gauge being operable to measure the strain applied to the elongate member, to

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thereby enable the amount of strain applied to the section or sections of fibre including one or more gratings and hence the wavelength of the or each grating in the tuneable optical filter to be inferred.

49. An optical spectrum analyser according to any of claims 1 to 47 in which the optical spectrum analyser further comprises optical calibration apparatus for calibrating the peak wavelength of the or each grating in the tuneable optical filter.

50. An optical spectrum analyser according to claim 49 in which the optical calibration apparatus comprises: an optical fibre coupler; a first section of fibre having a first reference Bragg grating inscribed therein, the said section of fibre being communicatively connectable to one leg on one side of the calibration coupler; and an optical source communicatively connected to one leg on the second side of the calibration coupler.

51. An optical spectrum analyser according to claim 50 in which the peak wavelength of the first reference grating falls within the wavelength tuning range of one of the gratings in the tuneable optical filter.

52. An optical spectrum analyser according to claim 51 in which a further reference grating is provided in a further section of fibre for each further grating in the tuneable filter, the peak wavelength of each further reference grating falling within the wavelength tuning range of the corresponding grating.

53. An optical spectrum analyser according to claim 52 in which the further section or sections of fibre are each communicatively connectable to the calibration coupler in place of the first section of fibre, each further reference grating thereby replacing the first reference grating.

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54. An optical spectrum analyser according to any of claims 50 to 53 in which the or each reference grating is athermalised, or the peak wavelength of the or each reference grating is known at a specified temperature, from independent calibration.

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55. An optical spectrum analyser according to any of claims 50 to 54 in which the optical source is a light emitting diode, the optical output spectrum of the light emitting diode including the peak wavelength of the or each reference grating.

56. An optical spectrum analyser according to any of claims 50 to 55 in which the optical calibration apparatus is connectable to the optical spectrum analyser between the input length of fibre and the tuneable optical filter, to thereby provide an alternative input signal to the optical spectrum analyser, the second leg on one side of the calibration coupler being communicatively connectable to the input length of fibre and the second leg on the second side of the calibration coupler being communicatively connectable to the one leg on one side of the first coupler.

57. An optical spectrum analyser according to claim 49 in which the optical calibration apparatus comprises: an optical fibre coupler; a first section of fibre having a first reference grating inscribed therein, the said section of fibre being communicatively connectable to one leg on one side of the calibration coupler; first and second photodetectors communicatively connected to the second leg on one side and one leg on the second side of the calibration coupler respectively; and means operable to compare the output signals of the photodetectors.

58. An optical spectrum analyser according to claim 57 in which the optical spectrum of the first reference grating falls within the wavelength tuning range of one of the gratings in the tuneable optical filter.

59. An optical spectrum analyser according to claim 58 in which a further reference grating is provided in a further section of fibre for each further grating in the tuneable filter, the optical spectrum of each further reference grating falling within the wavelength tuning range of the corresponding grating.

60. An optical spectrum analyser according to claim 59 in which the further section or sections of fibre are each communicatively connectable to the

calibration coupler in place of the first section of fibre, each further reference grating thereby replacing the first reference grating.

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61. An optical spectrum analyser according to any of claims 57 to 60 in which the reflectivity of the or each reference grating varies as a function of wavelength across its spectral bandwidth, such that the intensity of an optical signal reflected by a reference grating is dependent on the wavelength of the optical signal.

62. An optical spectrum analyser according to claim 61 in which the or each reference grating has a plurality of reflectivity peaks included within its spectral profile.

63. An optical spectrum analyser according to claim 62 in which the or each reference grating is a sampled grating.

64. An optical spectrum analyser according to claim 62 in which the or each reference grating is a moiré grating.

65. An optical spectrum analyser according to claim 62 in which the or each reference grating comprises an array of uniform period Bragg gratings.

66. An optical spectrum analyser according to claim 61 in which the or each reference grating is a chirped Bragg grating.

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67. An optical spectrum analyser according to any of claims 57 to 66 in which the or each reference grating is athermalised.

68. An optical spectrum analyser according to any of claims 57 to 67 in which the optical calibration apparatus is connectable to the optical spectrum analyser in place of the or a photodetector within the optical detection means, the first photodetector detecting a part of an optical input signal reflected by the tuneable optical filter and the second photodetector detecting the said part of the input signal reflected by the tuneable optical filter and the reference

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69. An optical spectrum analyser according to claim 68 in which the outputs of the photodetectors are connected to the means operable to compare the output signals, the said means being operable to calculate the ratio of the output signal of the first photodetector to that of the second photodetector, the ratio being indicative of the wavelength of the detected optical signal.
70. An optical spectrum analyser according to claim 49 in which the optical calibration apparatus comprises: an in-fibre wavelength division multiplexing (WDM) device, one leg on one side of the WDM device being communicatively connectable to the second leg on the second side of the first coupler; a first section of fibre having two in-fibre Bragg gratings inscribed therein and communicatively connected to one leg on the second side of the WDM device; an optical fibre coupler, one leg on one side of the coupler being communicatively connected to the second leg on the one side of the WDM device; a broadband optical source communicatively connected to one leg on the second side of the calibration coupler; a second section of fibre having a reference grating inscribed therein and communicatively connected at one end to the second leg on the second side of the calibration coupler; and a photodetector communicatively connected to the other end of the second section of fibre.
71. An optical spectrum analyser according to claim 70 in which the peak wavelengths of the gratings are separated by more than their individual wavelength tuning ranges.
72. An optical spectrum analyser according to claim 71 in which the peak wavelength of the first grating is within the wavelength tuning range of the tuneable optical filter.
73. An optical spectrum analyser according to claim 72 in which the peak wavelength of the first grating is within the 1540 nanometers to 1560 nanometers wavelength range.

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74. An optical spectrum analyser according to any of claims 71 to 73 in which the peak wavelength of the second grating is within the 1290 nanometers to 1310 nanometers wavelength range.
75. An optical spectrum analyser according to any of claims 70 to 74 in which the optical source is a broadband light emitting diode, the optical spectrum of the light emitting diode including the peak wavelength of the second grating.
76. An optical spectrum analyser according to any of claims 70 to 75 in which the photodetector is operable to detect an optical signal reflected by the second grating.
77. An optical spectrum analyser according to any of claims 70 to 76 in which the optical spectrum of the reference grating includes a plurality of passbands, such that only wavelengths of light which correspond to the wavelengths of the passbands are transmitted to the photodetector.
78. An optical spectrum analyser according to any of claims 70 to 77 in which the reference grating is athermalised, or the wavelength offset due to temperature effects is deduced from the temperature experienced by the reference grating, the exact wavelength of the reference grating thereby being determinable.
79. An optical spectrum analyser according to claim 77 or 78 in which the reference grating comprises a sampled grating.
80. An optical spectrum analyser according to claim 77 or 78 in which the reference grating comprises a moiré grating.
81. An optical spectrum analyser according to claim 77 or 78 in which the reference grating comprises a chirped Bragg grating.
82. An optical spectrum analyser according to any of claims 15 to 81 in which the or each optical fibre coupler is a 50:50 2x2 optical fibre coupler.

83. An optical spectrum analyser according to claim 82 in which the ends of any unconnected legs on any of the couplers are terminated with an angled cleave, to thereby substantially reduce any optical reflections from the said ends.

84. An optical spectrum analyser according to claim 82 in which the ends of the said unconnected legs are terminated in an index matching compound, to thereby substantially reduce any optical reflections from the said ends.

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85. An optical spectrum analyser according to any of claims 1 to 10 in which the axial force is compression.

86. An optical spectrum analyser according to any of claims 1 to 12 in which the optical signal selected by the tuneable optical filter is transmitted by one grating

87. A tuneable optical filter comprising: first and second in-fibre Bragg gratings inscribed in first and second sections of optical fibre respectively, the spectra of the gratings having different peak wavelengths, and means operable to apply a variable axial force to one or each of the first and second sections of fibre, to thereby tune the peak wavelength of the or each grating over a desired wavelength range, wherein the wavelength tuning range of the first grating is adjacent in wavelength space to the wavelength tuning range of the second grating, such that the combined tuning range of the gratings is greater than the tuning range of one grating.

88. An optical spectrum analyser substantially as described above with reference to the accompanying drawings.

89. A tuneable optical filter substantially as described above with reference to the accompanying drawings.

90. Any novel subject matter or combination including novel subject matter disclosed herein, whether or not within the scope of or relating to the same invention as any of the preceding claims.